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A Data Acquisition and Instrument Control System for Laboratory Tests of an Ion Beam Source

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

During the 1970's, the Air Force developed an ion beam source for use in spacecraft discharging experiments. In addition to the flight instruments, several models were developed for laboratory tests conducted at the Air Force Geophysics Laboratory. Over the past several years, the research methods used for the Satellite Positive Ion Beam System (SPIBS) tests have evolved from manual techniques for experiment control and data recording to the present use of a real-time, computer-based system. This system can perform data acquisition functions and, in addition, has experiment monitoring instrument control capabilities.
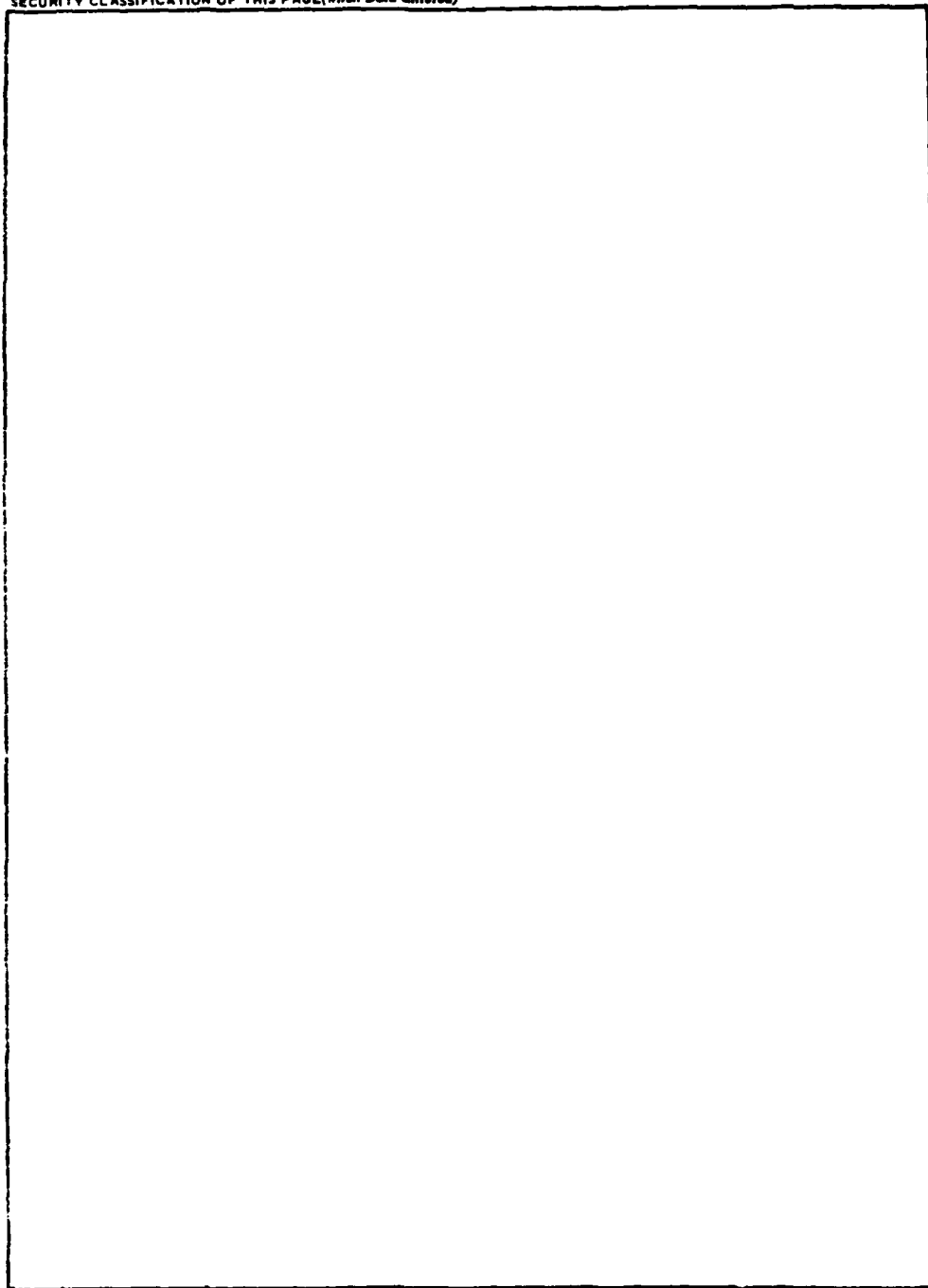
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Preface

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and criticism given throughout the preparation of this report. We also would like
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Illustrations

A Data Acquisition and Instrument Control System
for Laboratory Tests of an Ion Beam Source

1. INTRODUCTION

During the 1970's, the Air Force developed an ion beam source for use in spacecraft discharging experiments.[1,2] In addition to the flight instruments, several models were developed for laboratory tests conducted at the Air Force Geophysics Laboratory. Over the past several years, the research methods used for the Satellite Positive Ion Beam System (SPIBS) tests have evolved from manual techniques for experiment control and data recording to the present use of a real-time, computer-based system. This system can perform data acquisition functions and, in addition, has experiment monitoring and instrument control capabilities.

2. SPIBS BACKGROUND

The Satellite Positive Ion Beam System (SPIBS; Figure 1) is a particle ejector capable of emitting a beam of positively charged ions. The ejector uses a Penning-type discharge to produce ions. This design requires from 25 to 60 W to produce a

1. Masek, T. D., and Cohen, H. A. (1978) Satellite positive ion beam system, J. Spacecraft and Rockets, 15:27-33.

2. Stevens, J. R., and Vampola, A. L. (1978) Description of the Space Test Program P78-2 Spacecraft and Payload, SAMSO-TR-78-24, The Aerospace Corporation, El Segundo, California.

beam current range of 0.3 to 2.0 mA at energies of 1 and 2 keV. In addition, the ion beam system has a heated wire neutralizer that allows electron emission alone, or in combination with a positive ion beam to form a neutral plasma.

Figure 1. Satellite Positive Ion Beam System (SPIBS): Charged Particle Ejector Mounted on a Power Processor Assembly

Laboratory rests on the SPIBS are conducted using a vacuum chamber to simulate a space environment. The prototype model (Figure 2), the first functional version developed for preliminary experiments (1975-76), was tested in the vacuum chamber and controlled by power supplies outside the chamber. Instrument response was measured by analog meters and data were recorded by hand, requiring one person to initate commands and read responses, and another person to record results. (Table 1 shows the instrument commands.) This involved considerable time to control, monitor, and record data for 18 channels of output (Table 2).

In developing the flight model, the power supplies were reduced in size and integrated into a power processor so that the particle ejector could be mounted directly on the processor. The entire unit could now be placed inside the vacuum chamber. This required the development of a control unit which would have the

capability of sending digital commands and receiving analog values (as a rough approximation of the commanding circuitry on a space vehicle payload). The control unit registered output on a one-channel digital voltmeter, thus still requiring manual sequential switching for readings of data.

Figure 2. SPIBS Prototype: Charged Particle
Ejector

The data recording system developed for these early stages of experimentation was limited by the time required to complete the command-response-record cycle. The system did not have the capability of recording transient phenomena and did not allow comparisons of channels at the same time. As a result, recorded phenomena could only be viewed as isolated occurrences and were an incomplete description of events.

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Table 1. SPIBS Instrument Commands[*]

Command	Function
1. Instrument on[a]	Turns on instrument power
2. Instrument off[a]	Turns off all instrument power
3. Expellant valve open	Opens solenoid valve
4. Expellant valve closed	Closes solenoid valve
5. Cathode heater preheat	Turns on the cathode heater to Level 1 and turns on discharge supply
6. Ion gun power on	Turns on the ion gun power
7. Ion gun power off	Turns off the ion gun power
8. Beam voltage Level 1	Sets the beam power supply to 1000 V
9. Beam voltage Level 2	Sets the beam power supply to 2000 V
10. Keeper off	Turns the keeper supply off
11. Discharge current and neutralizer emission Level 1	Sets the discharge current reference to achieve 20 mA current; sets neutralizer emission level to 0.4 mA
12. Discharge current and neutralizer emission Level 2	Sets the discharge current reference to achieve 125 mA current; sets neutralizer emission level to 1.2 mA
13. Discharge current and neutralizer emission Level 3	Sets the discharge current reference to achieve 200 mA current; sets neutralizer emission level to 2.2 mA
14. Neutralizer emission Level 4	Sets neutralizer emission level to 2 μA
15. Neutralizer emission Level 5	Sets neutralizer emission level to 20 μA
16. Neutralizer No. 1	Selects neutralizer filament No. 1
17. Neutralizer No. 2	Selects neutralizer filament No. 2
18. Neutralizer heater on	Turns on the neutralizer cathode heater on
19. Neutralizer heater off	Turns off the neutralizer bias
20. Neutralizer bias off	Turns off the neutralizer bias power supply
21. Neutralizer bias positive	Sets the neutralizer bias for positive polarity
22. Neutralizer bias negative	Sets the neutralizer bias for negative polarity
23. Neutralizer bias Level 1	Turns on the neutralizer bias to 10 V
24. Neutralizer bias Level 2	Turns on the neutralizer bias to 25 V
25. Neutralizer bias Level 3	Turns on the neutralizer bias to 100 V
26. Neutralizer bias Level 4	Turns on the neutralizer bias to 500 V
27. Neutralizer bias Level 5	Turns on the neutralizer bias to 1000 V
28. High voltage off	Turns off the beam and accel power supplies
29. Cathode conditioning	Turns on the cathode heater to Level 2

[*]From Masek, T. (1978) Satellite Positive Ion Beam System, Air Force Geophysics Laboratory, AFGL-TR-78-0141, pp 106-107.

[a]In the SPIBS instrument, instrument on/off is implemented by connecting or disconnecting 28 V input power.

Table 2. SPIBS Analog Output Channels[*]

Channel No.	Description	Actual Value for 5 V Output, ± 5%
1	Beam current	2.5 mA (± 2%)
2	Beam voltage	2500 V
3	Discharge current	250 mA
4	Discharge voltage	50 V
5	Keeper current	250 mA
6	Keeper high voltage	1000 V
7	Keeper low voltage	50 V
8	Cathode heater current	5 A
9	Accel current[a]	2.5 mA
10	Decel current[a]	2.5 mA
11	Neutralizer heater current	5 A
12	Neutralizer bias voltage	1000 V
13	Neutralizer emission[b]	2.5 mA (± 10%)
14	SPIBS net current[b]	2.5 mA (± 10%)
15	Tank pressure	1500 psia
16	Power processor temperature	See calibration curve
17	PPA ac inverter current	1.5 A
18	PPA ac inverter voltage	50 V

[*]From Masek, T. (1978) Satellite Positive Ion Beam System, Air Force Geophysica Laboratory, AFGL-TR-78-0141, p 100.

[a]To indicate anomolous condition.

[b]In three ranges: 2.5 to 25 μA; 25 μA to 250 μA to 2.5 mA.

3. AUTOMATIC DATA RECORDING

A digital data printer was added in an attempt to incorporate automatic data recording. This increased the capability of the system because it released researchers from the responsibility of manually recording data, giving them more control over the experiment. Although the printer was capable of recording 20 values per sec, the data transfer from the voltmeter to the printer was limited by the analog-to-digital signal conversion in the voltmeter (five conversions, or channels, per sec). Another drawback was that unavoidable arcing within the

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vacuum chamber (due to ion beam emissions) was liable to disrupt the printer synchronization; under these circumstances the data were unreliable. Also, the data required much time for analysis: digital data has to be converted to engineering units and then graphed.

Since data recording was limited by the time required for the analog-to-digital conversion, analog strip-chart recorders were used to record output from the SPIBS (1977-79). This represented a major improvement in data acquisition for SPIBS experiments, in that all 18 channels could be individually, simultaneously, and permanently recorded. (Three six-channel recorders were used.) The recorders allow a measurement ot 0.05 V precision relative to a range of 0 to 5 V telemetry output from the SPIBS (one part in one hundred). The frequency response of the recorders is in the range of 60 to 100 Hz.

Although the use of strip-chart recorders increased the amount of recorded data, they required frequent calibration to maintain accuracy. The recorders allowed a certain amount of control over the time scaling by varying the chart speed, but it was difficult to identify the changes during data analysis. Although the data now included simultaneous recordings of the analog channels, comparisons between channels were a problem, particularly between channels on different recorders. Figure 3 shows an example of strip-chart recorder output.

4. COMPUTER-BASED DATA ACQUISITION AND CONTROL

The use of strip-chart recorders expanded the scope of the SPIBS experimentation by providing a continuous record of instrument output and a reasonable frequency response. However, the manpower required for operation and the time required for data reduction limited their usefulness. In 1980, a computer-based Data Acquisition and Instrument Control System (DAICS) was installed to take advantage of more efficient methods of data processing and to increase experiment control (Figure 4). It was designed to simulate satellite ground control systems, and thus had data acquisition, monitoring, and instrument control capabilities. The system is configured around a Digital Equipment Corporation PDP11/34A processor with a video terminal and a hardcopy terminal for input/output functions; magnetic disk and tape storage; and a graphics pen plotter. (Appendix A contains a list of the DAICS hardware.)
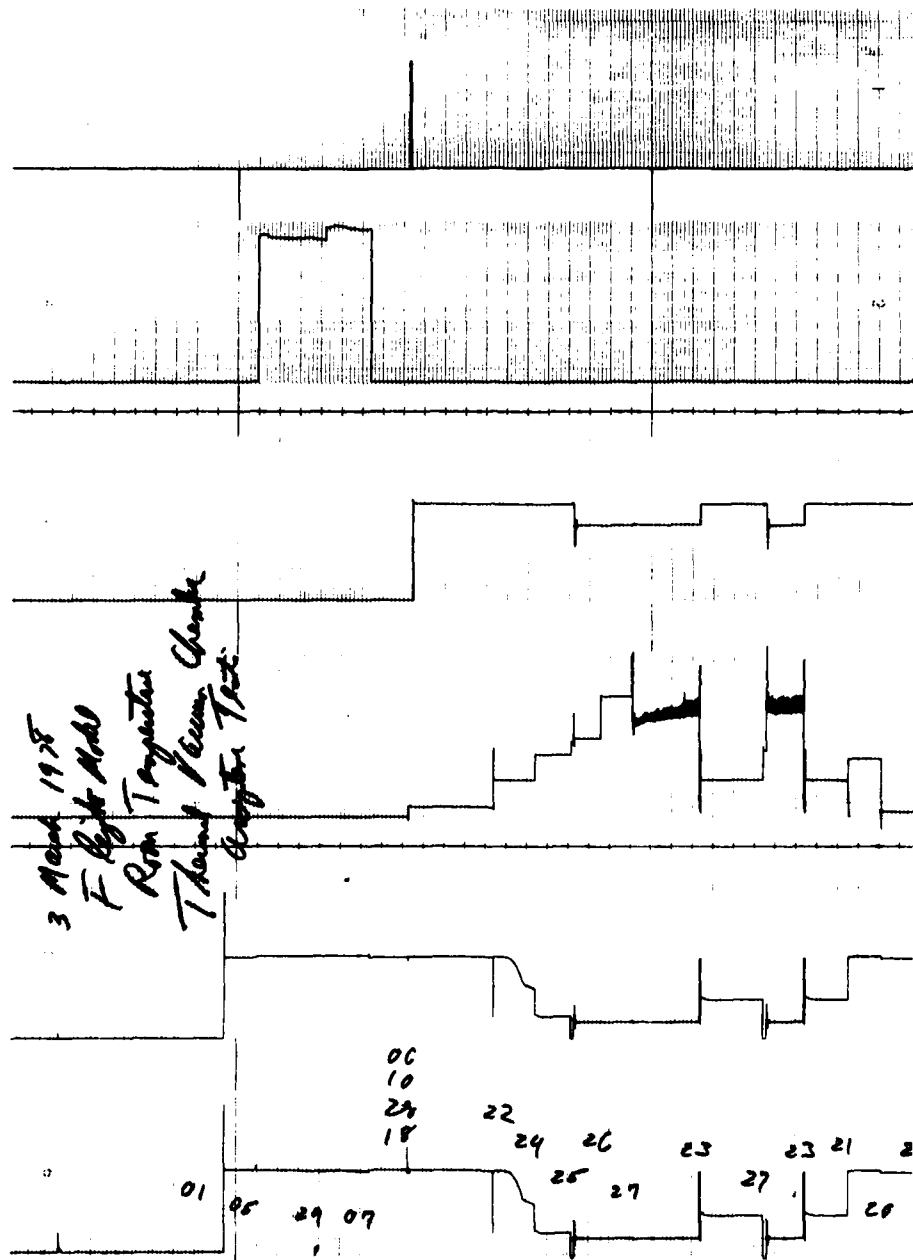
Figure 3. Strip-chart Recorder Output. Channels represented (left to right): net current, neutralizer emission, neutralizer bias voltage, neutralizer heater current, cathode heater current, keeper low voltage. Each graph column is divided into 50 segments (5 V total, 0.1 V per segment). Chart speed is 1 mm/sec. Handwritten numbers indicate commands given
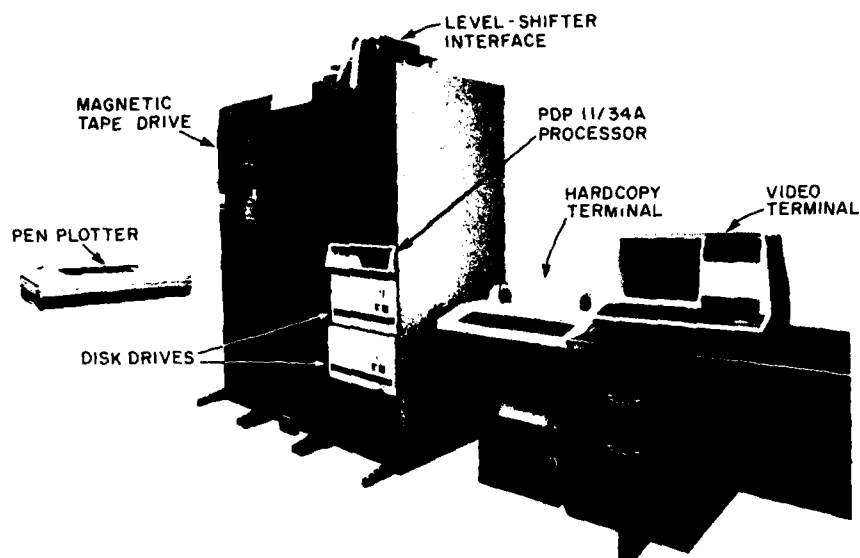
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Figure 4. Data Acquisition and Instrument Control System (DAICS)

Computerized data acquisition requires both analog-to-digital signal conversion and sufficient data storage to allow reasonable test lengths at typical sampling rates. The DAICS has a 16-channel A/D converter with a 48-channel multiplexer, which combine to give 64 channels of A/D input. Digitized data is stored on a removable, 5.2 Megabyte disk. This allows storage of up to 5 hr of data on one disk under the present data structure (two words per sample, approximately 75 samples per sec). In addition, the DAICS has an industry-standard magnetic tape drive; stored data can be transferred from disk to tape, allowing data reduction on other systems.

Any comparison of the two methods of data acquisition (strip-chart recorder and A/D conversion) must take into account the basic difference between the two systems. Strip-chart recorders give a continuous record; the analog-to-digital conversion is a sample and hold process. In the A/D conversion process, an analog signal from the SPIBS is amplified and sampled. The signal is held and compared by successive approximation to a second analog signal generated by the A/D converter. The second signal corresponds to a digital value that is stored on disk when the comparison process is complete. One complete sampling and conversion cycle takes 22 m/sec.

Although the A/D converter is capable of digitizing roughly 45,000 samples per sec, the system is limited by the software because of the time necessary to process the instructions for data manipulation and storage. While the effective

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frequency response of the DAICS is lower than the analog recorder response
(5 - 10 Hz compared to 60 - 100 Hz), the data storage and reduction advantages
gained through computerized data acquisition are considerable. The DAICS was
designed to give a sample rate at least equivalent to the telemetry system support-
ing the satellite model SPIBS on board the SCATHA (Satellite Charging at High
Altitudes) satellite (16 samples per sec).

The DAICS gives a precision of measurement that is greater than the precision
possible with the strip-chart recorders. The A/D converter uses 12-bit digitiza-
tion, allowing a comparison precise to one part in 4096. The precision is reduced
to one part in 1024 because of input noise (approximately 10 mV). This results in
measurements of 0.01-V precision, based on the 10.24-V input range of the A/D
converter. (Table 3 shows a comparison of the DAICS with the strip-chart recorders).

Table 3. Comparison of DAICS and Analog Strip-chart
Recorders. The frequency response is given in differ-
ent units to emphasize the difference between the two
methods of data acquisition

	DAICS (A/D conversion)	Strip-Chart Recorder (analog recording)
Frequency Response	75 samples per sec*	60 - 100 Hz
Precision of Measurement	0.01 V	0.05 V

*Under the present software configuration

The system was designed to provide monitor and control functions. Monitor-
ing is accomplished through real-time display of digitized data on a video terminal,
and through command echoing and warning message printing on a hardcopy ter-
minal. The operator can control the experiment by entering commands on the video
terminal. The system can also be commanded from the hardcopy terminal, but in
this case, the video terminal is bypassed and there is no display of sampled data.

When commands are entered on a terminal, the processor transmits a signal
to a 32-channel digital input/output circuit that generates Transistor-Transistor
Logic compatible signals (5V). The input/output circuit is connected to a level-
shifter interface where the signal is increased to 28 V (as required for SPIBS opera-
tion). The DAICS has an additional four channels of D/A output which can be used
to control voltage-driven devices, or output data to an X/Y plotter or graphics video
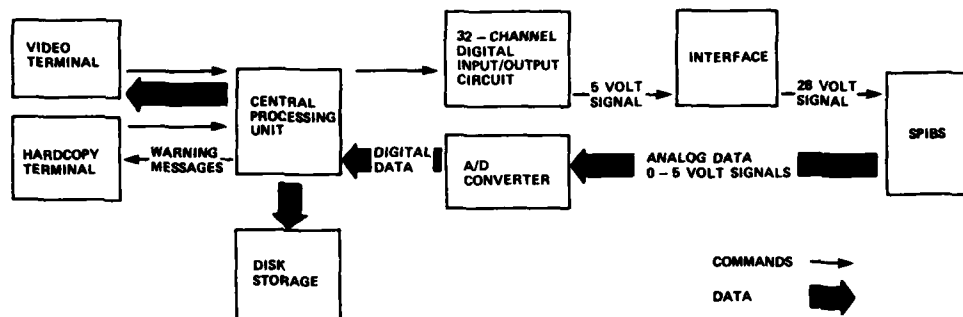terminal. Figure 5 shows the DAICS configuration.

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Figure 5. Data Acquisition and Instrument Control System. The system allows
the user to monitor the experiment and enter commands at a terminal, while
analog data is digitized and stored in real-time

5. SOFTWARE

The operating system (or monitor) chosen for the DAICS is RT11, a single
user, real-time system with foreground/background capabilities. The foreground/
background monitor allows storage of two programs in memory at the same time.
One program is identified as the foreground job, thus giving it priority. Programs
can be structured as groups of routines which can be moved back and forth between
disk and main memory as required for particular tasks.

The software package developed for the SPIBS experiment is a combination of
programs which provides real-time data sampling, command, and control opera-
tions, as well as data reduction capabilities. The foreground program, written in
assembly language, handles data acquisition and storage, data monitoring, and
instrument control functions. The background program, written in FORTRAN IV,
handles terminal interaction, and storage and handling of experiment configurations.
Although the software was developed for the SPIBS experimentation, it can be used
with any experiment that uses low-level analog signals.

A real-time program must be treated differently than the usual linear program.
Although the real-time program can be viewed as a set of independent processes
operating simultaneously, in actuality the computer can do only one thing at a time.
Therefore, only one process can be running at any one time. The processes are
then competing for system resources (that is, use of the central processing unit).

Processes communicate with other processes to pass information and to estab-
lish timing relationships (synchronization). This job of scheduling and communica-
tion between processes is handled by the operating system. In addition to scheduling
and communication, the monitor provides other services, including input and output

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functions, file manipulation, and data conversion. The monitor itself consists of many independent processes which are competing with the application program for use of the central processing unit.

Within the framework established by the foreground/background monitor, the operating system uses a three-level hierarchy to schedule processes: mainline, completion, and interrupt. The mainline has the lowest priority, performing display and command reception functions. The completion routines can interrupt the mainline process; these routines interpret instructions, synchronize processes, and update data structures. Interrupt routines, such as those controlling sampling and conversion, have the highest priority. Interrupts are synchronous (initiated by the program) or asynchronous (triggered by an external device, such as the system clock or an external event). This scheduling system allows a complex system of tasks to be executed in real-time.

5.1 Experiment Control

The software has been designed to allow a person with minimal programming experience to control the experiment. Interactive processing gives direct control over the experiment from a terminal. A series of simple commands directs the major processes; command definitions are available through a "HELP" command (Figure 6). The researcher can define experiment parameters, and then generate commands as required to operate the instrument while monitoring experiment conditions and results.

The program allows a great deal of flexibility in experiment design. It was designed to use a default experiment configuration automatically, but the configuration can be changed. Information given in response to a series of questions describes the experiment parameters (Figure 7): number and labeling of analog channels to be sampled; sampling intervals for each channel; and warning levels for sampled input. New information given for experiment parameters does not change the default file. If the parameters are changed, the new configuration can be saved in a separate file that can be retrieved for later use.

5.2 Data Acquisition

Analog data is sampled, digitized, and stored on disk in real-time. This process is the result of a number of foreground routines which interact to control the A/D converter and the data transfer. During each sampling cycle, the software is capable of accepting and manipulating digitized values for all of the channels. Figure 8 shows the processes that control sampling and data storage.

```
ANY CHANGES TO COMMAND-AD FLAGS INVOLVING THIS CHANNEL? N
SC4>HELP

   Commands available:
   STA   Start sampling
   STO   Stop sampling
   C     External command
   END   End session
   CHA   Define A/D channel
   CON   Show configuration
   DEF   Define block command
   SAV   Save configuration
   GET   Get configuration

   For help on each item, type  HELP item

SC4>HELP CHA

   CHA n    where n is a number<64  or a 1-3 letter mnemonic

   Define a configuration for A/D channel n, including compound flags.

SC4>
```

Figure 6. Video Terminal Display: Software Commands. The
"HELP" command produces a listing of the acquisition, moni-
toring, and control software commands; the prompt ">C4 >"
refers to the satellite model particle beam system. The "HELP"
command used with a software command produces the command
definition

```
SC4>CHA 15

    DO YOU WANT TO REMOVE THIS CHANNEL? (Y OR N): N
    SAMPLE INTERVAL, MSEC  OLD: 5000  NEW? (Y OR N): N
    DISPLAY INTERVAL, SAMP OLD:    1  NEW? (Y OR N): N
    RED HIGH LIMIT (MV)    OLD: 5120  NEW? (Y OR N): Y
    ENTER NEW VALUE: 4000
    RED LOW LIMIT  (MV)    OLD: 1500  NEW? (Y OR N): N
    YELLOW HIGH LIMIT (MV) OLD: 5120  NEW? (Y OR N): Y
    ENTER NEW VALUE: 3000
    YELLOW LOW LIMIT (MV)  OLD: 1600  NEW? (Y OR N): N
    MNEMONIC  OLD: TMP  NEW? (Y OR N): N
    NAME OLD:TEMPERATURE       NEW? (Y OR N): N

    ANY CHANGES TO COMPOUND FLAGS INVOLVING THIS CHANNEL? N

    ANY CHANGES TO COMMAND-AD FLAGS INVOLVING THIS CHANNEL? N
    SC4>
```

Figure 7. Video Terminal Display: A/D Channel Definition.
Interactive processing allows the researcher to define the
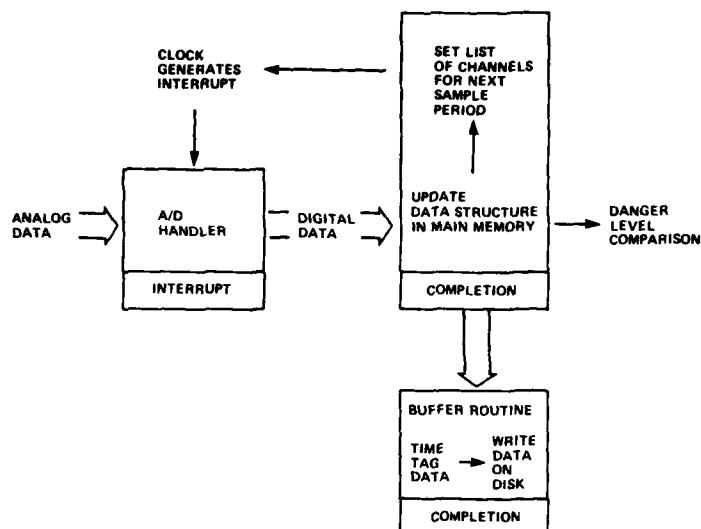parameters for data acquisition

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Figure 8. Foreground Processes For Sampling and Data Storage. Once sampling is initiated from the terminal the data conversion-and-storage loop will continue until sampling is stopped from the terminal. The programmable clock calls the A/D handler, a software routine that controls the A/D converter. Analog input is digitized, then a second routine transfers the digitized data to main memory and calls a subroutine that sets the list of channels for the next time. The data in main memory is time-tagged and written on a disk, and compared to values established for danger levels

When testing is started, all channel values are recorded immediately. After the first set of samples, each sampling and digitization cycle is initiated by a programmable clock, at intervals according to user specifications. The A/D converter is directed by a monitor-controlled interrupt routine (the A/D device handler). When the digitization is finished, a completion routine updates the data structure in main memory. The data is transferred to a buffer (temporary storage), time-tagged, and then written on a disk. Once the data structure has been updated, the channels are set for the next sampling period, and the central processing unit is set for the next conversion.

The current program configuration can process up to 32 channels of analog data. The present experiment configuration uses 22 channels: 18 channels come directly from the SPIBS; 4 channels are connected to particle detection equipment in the vacuum chamber. Figure 9 shows a listing of the channels and channel parameter.

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Figure 9. Video Terminal Display: SPIBS Experiment Configuration.
Channel parameters for ion beam system output and particle detection
equipment: channel number, sample interval (milliseconds), display
rate (samples averaged/second), red (danger) high level (millivolts),
red low level (millivolts), yellow (caution) high level (millivolts),
yellow low level (millivolts), mnemonic, channel description

Sampling rates are specified by the researcher. The range of rates extends
from one sampling period every 23 sec to one sample every 22 msec. The maxi-
mum sampling rate is dependent upon the number of channels operating. Thus,
when operating with a fully loaded configuration, the fastest rate possible is one
every 50 msec. Table 4 shows the minimum sample interval according to the
number of channels operating.

5.3 Monitoring

The DAISC gives the researcher more experiment control than was allowed
using other methods. Experiment conditions, such as intrument output and environ-
ment characteristics, can be monitored from a video terminal. The system also
provides for an audio-visual warning system that is activated according to pre-
set conditions.

Table 4. Minimum Sample Intervals According to
Number of Channels Operating. The table indicates
intervals required to insure storage of all data;
shorter intervals will result in some data loss

No. of Channels	Sample Interval (msec)
1	45 45
5	50 50
10	50
15	60
20	70
25	70
32	70

Figure 10 shows the video terminal display during sampling. The upper half of the screen is dedicated to real-time display of analog signals. Channels are identified by mnemonics. The integer values represent millivolt measurements of sampled, telemetry input signals. As with sampling rates, the rate of display update can be specified by the operator. The fastest rate of update is once per second; the values displayed are averages taken over the update period. In addition, the elapsed time is shown in hours, minutes, and seconds. The lower half of the screen shows prompts and commands.

Foreground and background processes combine to provide the monitoring capabilities (Figure 11). The operator can specify caution and danger levels for the analog output from the instrument. Sampled, digitized data is compared to these values and stored in a buffer as part of the foreground processing. Any warnings required as a result of the comparisons are also stored in the buffer. Background processing displays the data and also prints out warnings as necessary.

Warning messages (flags) are printed on the hardcopy terminal and an alarm sounds when caution or danger levels are reached (Figure 12). The program also prints out commands generated from the terminal. The warning system has been particularly valuable for the SPIBS experimentation. For example, the temperature of the power processor assembly is critical. Using earlier experiment techniques, it was necessary for a person to monitor the temperature constantly, in addition to the other tasks required in running the experiment. Computerized monitoring calls attention to experiment conditions as required, leaving personnel free for other experiment duties.

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Additional flag comparisons can be invoked by using compound AD/AD flags or compound AD/command flags. The AD/AD condition allows the researcher to specify output voltage levels for two channels at the same time: if both levels are reached, a message is printed. The AD/command condition disenables a particular command when the specified channel reaches its designated level.
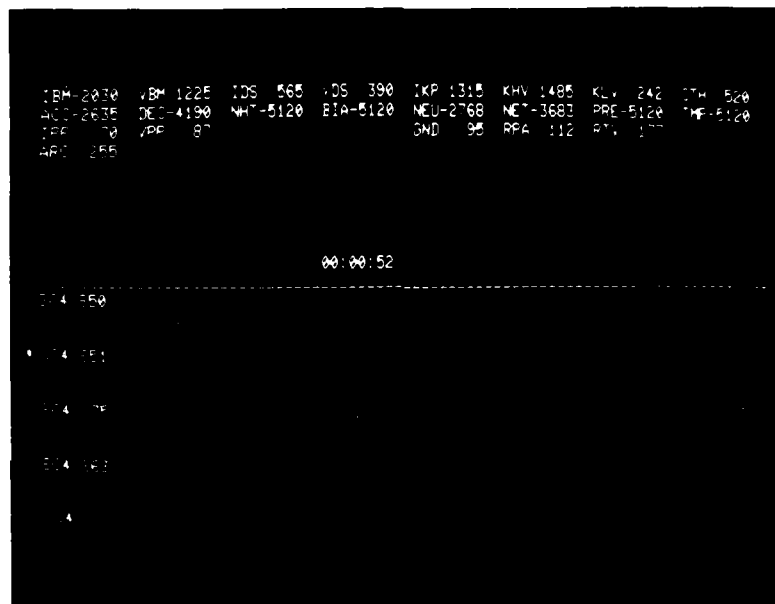

Figure 10. Video Terminal Display: Sampling Display. The data acquisition and instrument control software was written to allow the researcher to monitor the experiment and control the instrument from the same terminal. Channel mnemonics, integer values corresponding to telemetry input voltages (millivolts), and elapsed time are displayed on the upper half of the terminal screen. The lower half shows software prompts ("SC4 >") and commands
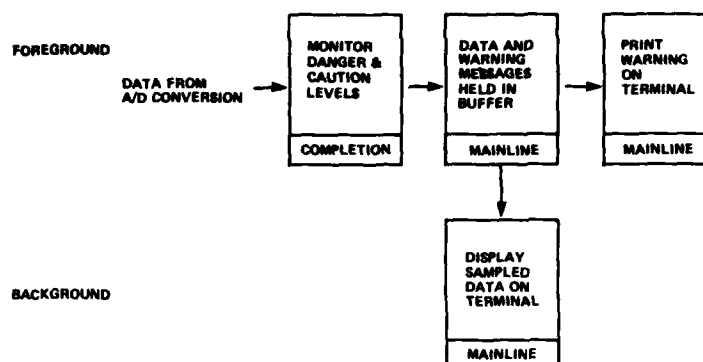
22

Figure 11. Foreground and Background Processes for Monitoring and Display Functions. The foreground/ background monitor allows sampling and danger level comparisons to continue in foreground processing, while the background process displays accumulated data and messages

```
00:06:18.000  CAUTION:  KLV
00:06:19.000  DANGER:   KLV
00:06:25.000  DANGER:   IPP
00:06:25.000  DANGER:   VPP
```

Figure 12. Hardcopy Output: Warning Messages. The monitor processing includes comparisons between sampled data and predetermined danger levels, and subsequent printing of warning messages. The output shows time, warning level, and channel mnemonic

5.4 Instrument Control

The system gives the researcher a quick, reliable, and flexible method of instrument control. Earlier methods involved simpler devices which did not give any indications that commands had been issued. Computerized instrument control is accomplished through a series of commands that are entered, and echoed, on a terminal. The commands used in the software for the ion beam experiments were developed as part of the SPIBS hardware design (Figure 13).

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COMMANDS

```
S50   SPIBS   SYSTEM POWER ON
S51   SPIBS   SYSTEM POWER OFF
S52   SPIBS   GAS VALVE OPEN
S53   SPIBS   GAS VALVE CLOSED
S54   SPIBS   ION BEAM ON
S55   SPIBS   ION BEAM OFF
S56   SPIBS   CATHODE CONDITIONING
S57   SPIBS   CATHODE PREHEAT
S58   SPIBS   1KV BEAM ENERGY
S59   SPIBS   2KV BEAM ENERGY
S60   SPIBS   KEEPER OFF
S61   SPIBS   NEUTRALIZER # 1
S62   SPIBS   NEUTRALIZER # 2
S63   SPIBS   NEUTRALIZER HEATER ON
S64   SPIBS   NEUTRALIZER HEATER OFF
S65   SPIBS   HIGH VOLTAGE OFF
S71   SPIBS   BEAM & NEUT. 0.3MA CURRENT
S72   SPIBS   BEAM & NEUT. 1.0MA CURRENT
S73   SPIBS   BEAM & NEUT. 2.0MA CURRENT
S74   SPIBS   NEUTRALIZER 0.008MA CURRENT
S75   SPIBS   NEUTRALIZER 0.02MA CURRENT
S78   SPIBS   NEUT. BIAS POSITIVE & ON
S79   SPIBS   NEUT. BIAS NEGATIVE & ON
S80   SPIBS   NEUT. BIAS OFF
S81   SPIBS   NEUT. BIAS 10V ENERGY
S82   SPIBS   NEUT. BIAS 25V ENERGY
S83   SPIBS   NEUT. BIAS 100V ENERGY
S84   SPIBS   NEUT. BIAS 500V ENERGY
S85   SPIBS   NEUT. BIAS 1KV ENERGY
```

Figure 13. Software Instrument Commands.
The SPIBS software allows the operator to
control the instrument from a terminal using
single commands (S50, S51, and so on)

Before the DAICS was installed, commands were issued relatively slowly, one
after another. The SPIBS software allows the researcher to control the instrument
with single or block (grouped) instructions (Figure 14) using short, coded commands.
A command is processed in both the foreground and background programs (Figure 15).
The software provides a command pulse length (100 msec) that meets the standard
established for satellite command systems.

5.5 Data Reduction

The DAICS allows rapid, accurate data reduction. This computerized data re-
duction provides a wide range of possibilities which can be accomplished in a much
shorter period of time than possible through manual reduction of strip-chart re-
corder data. Instrument output can be processed through a series of interactive
programs which provide plotting, calibration, printing, and data transfer functions.

24

```
888  SPIDS  INITIALIZE & OFF     s/c 11
     853
     851
     855
     858
     861
     864
     872
     880
     981
     860
     865
889  SPIDS  EXPELLANT INITIALIZE   s/c 6
     852
     WAIT 4
     853
894  SPIDS  NEUT. INITIALIZE & HEATER ON    s/c 5
     854
     860
     865
     879
     863
```

Figure 14. Block Commands. The operator can combine single commands, and other block commands, and implement them as a group by using short, coded commands. "s/c n" refers to the number of commands in the block (step count, number of commands). "wait 4" results in a pause of 4 sec before implementing the next command in the block
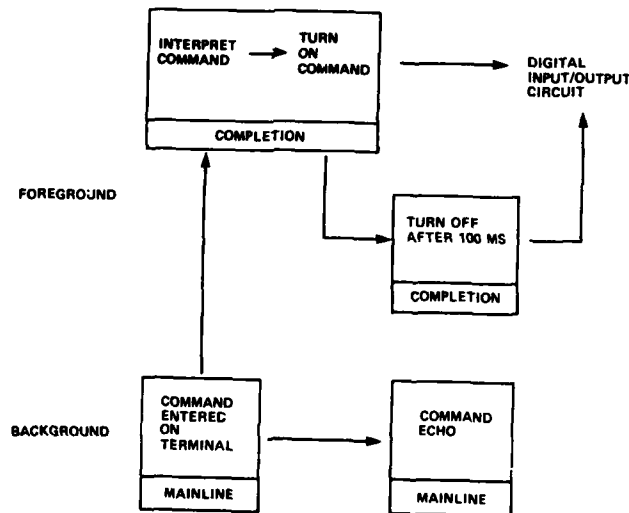

Figure 15. Foreground and Background Processes for Instrument Control. A command entered at the terminal causes the transmission of a 100 msec pulse to the digital input/output circuit

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The plot program will produce graphs of sampled data on a video graphics terminal or a pen plotter. One or two channels can be plotted against time. The time scale can be expanded or condensed to represent the entire test period or a small portion of it. In addition, on the pen plotter, one channel can be plotted against the other. Scaling is either automatic or user-specified.

Data can be plotted as uncalibrated instrument output (telemetry voltages), or can be converted to engineering units using calibration files. The calibration program allows the researcher to define calibration curves for the analog channels. Other programs print data on a line printer and transfer data from disk to magnetic tape for processing on other systems.

Appendix E contains examples of data reduction programming output.

6. CONCLUSION

A computerized Data Acquisition and Instrument Control System is being used for the Satellite Positive Ion Beam System experimentation. In changing from an analog recording system to an analog-to-digital conversion system, some accuracy has been lost, but greater experiment control has been established. The frequency response of the DAICS is somewhat lower, and its precision of measurement, somewhat greater than the capabilities of the strip-chart recorders. However, the reliability and flexibility of the computer system, combined with the instrument control, data storage, and data reduction capabilities, have significantly expanded the scope of the SPIBS laboratory experimentation. In addition, the system has the potential for development.

Acquired from Digital Equipment Corporation:

PDP 11/34A Processor (Extended Instruction Set, and memory mapping)

32 k words Solid State Memory (MOS) with parity

Programmable Clock (KW11-K)

A/D Input (64 channels)
- 16 channel A/D converter (AD11-K)
- 48 channel multiplexer (AM11-K)

Analog Output
- 4 channel D/A converter (AA11-K)

Digital Input/Output (32 channels)
- two 16 bit digital input-output (DR11-K)

Removable Disk Storage
- two 5. 2 M byte disk storage (RL01)

Magnetic Tape Drive (TME11-EA)
- 9 track, 800 bpi, 45 ips

Hardcopy Terminal - DECwriter (LA-36)
- 300 baud

Video Terminal - DECgraphic Scope (VT-55)
- 9600 baud

Instrumentation Buss Interface (IB11)
- for external instrument control and data collection
  (IEEE-488-1975 buss)

Supplementary Hardware:

Hewlitt Packard Digital Plotter (9872S)

Level-shifter Interface
   -circuitry designed to increase TTL level signals (5 V)
   -discrete command pulse level (28 V)

Appendix B

Data Reduction

This appendix contains examples of output from the plotting and printing programs designed for the Data Acquisition and Instrument Control System. All of the programs use interactive processing to define the parameters for the data processing.

Figures B1 through B4 and B6 through B8 show output from the plotting program. Figure B5 shows strip-chart recorder output for comparison with computer plots (Figures B6 through B8). Figure B9 shows output from the data printing program.
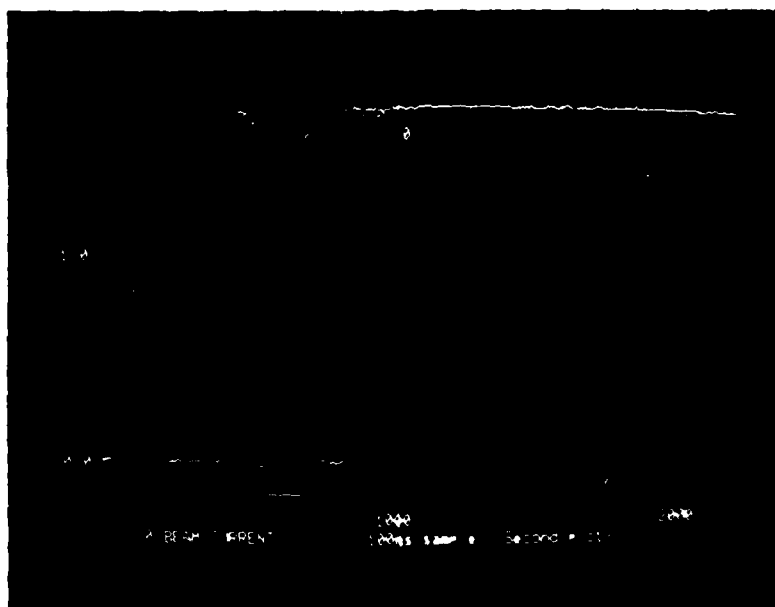
Figure B1. Video Terminal Display Showing a Calibrated Plot
of One Channel (beam current, mA) Plotted Against Time. The
plot program first produces output on the video terminal, then
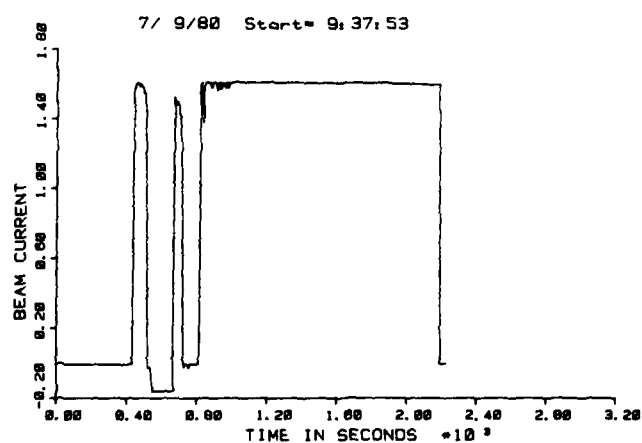on the pen plotter

Figure B2. Calibrated Pen Plot of One Channel
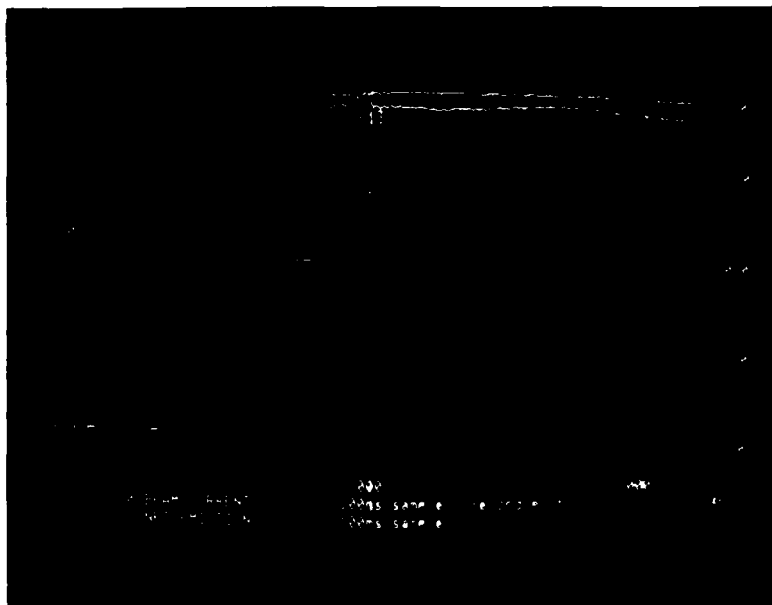(beam current, mA) Against Time. (Same event
as Figure B1)

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Figure B3. Video Terminal Display of Calibrated Plot of Two
Channels, Beam Current (mA) and Net Emission (μA), Plotted
Against Time
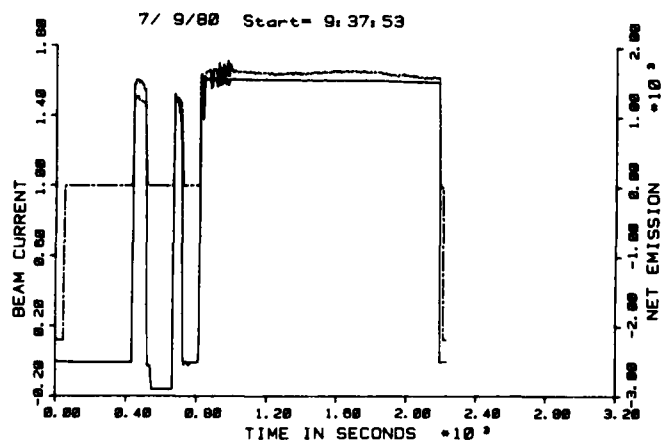

Figure B4. Calibrated Pen Plot of Two Channels,
Beam Current (mA) and Net Emission (μA) Against
Time. Beam current is represented with solid line.
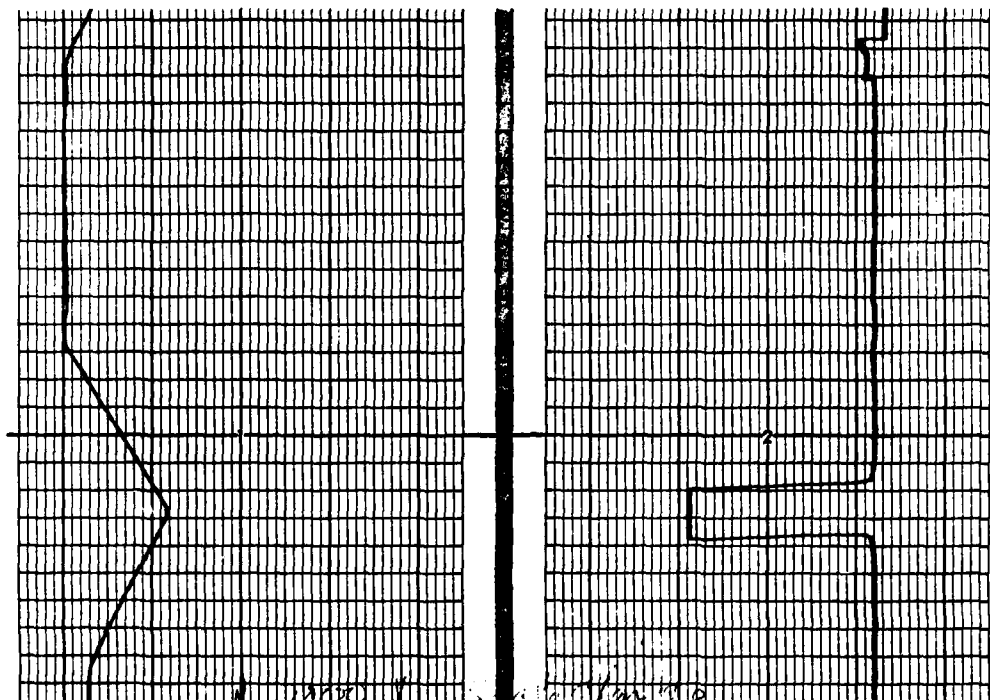(Same event as Figure B3)

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Figure B5. Strip-chart Record of Two Channels. (Left to right) potential
across a retarding grid on a Retarding Potential Analyzer (RPA), and
RPA electrometer. Each channel is recorded relative to the analog input range
of 0 to 5 V; the divisions represent 0.1-V segments. Chart speed is 1 mm/sec.
Once recorded on the strip-charts, data had to be converted to engineering
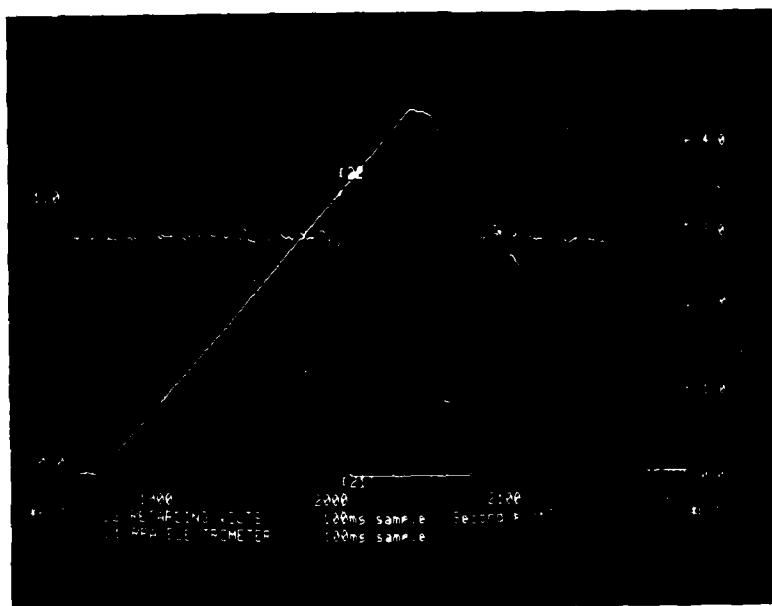units and graphed

Figure B6. DAICS Data Reduction Programming Output. A calibrated plot of an event similar to the one represented in Figure B5, as output on the video terminal (two channels, retarding potential and RPA electrometer, against time)
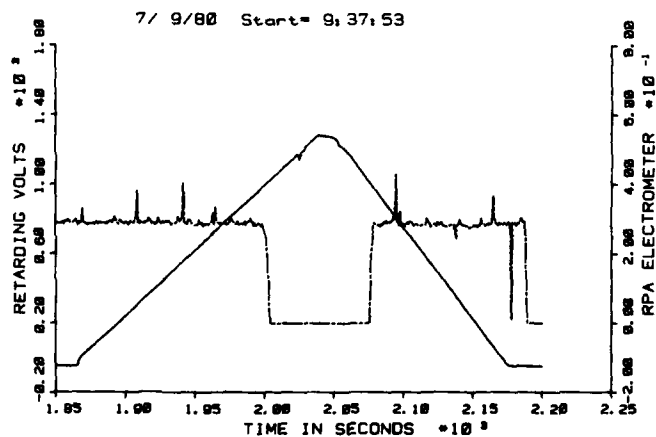

Figure B7. Pen Plot: Two Channels (retarding voltage, RPA electrometer) Against Time. (Same event as represented in Figure B6)
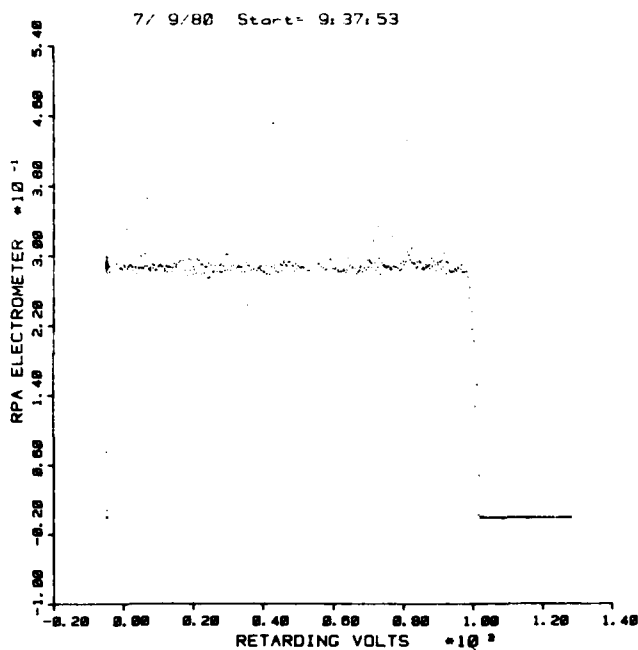
33

7/ 9/80 Start: 9:37:53

Figure B8. Pen Plot: One Channel (retarding voltage) Against a Second (RPA electrometer). (Same event as represented in Figures B6 and B7)

| CHANNEL NUMBER | 0 | 1 | | 4 | 15 | 21 |
TIME	IBM	VBM		IKP	TMP	RPA
710.000	1.35	948.		138.	34.7	2.944E-04
711.000	1.22	948.		138.	34.7	2.640E-04
712.000	1.13	948.		138.	34.7	2.584E-04
713.000	1.15	948.		138.	34.7	3.50SE-04
714.000	1.13	948.		138.	34.7	3.661E-04
715.000	1.10	948.		85.2	34.7	4.126E-04
716.000	1.11	948.		85.2	34.7	4.912E-04
717.000	0.228	948.		85.2	34.7	1.420E-04
713.000	0.187	948.		85.2	34.7	1.024E-04
719.000	0.194	948.		85.2	34.7	8.509E-05
720.000	CAUTION: CHANNEL 11		BIA			
720.000	-6.160E-03	948.		88.9	35.9	0.000
728.000	CAUTION: CHANNEL 0	IBM				
728.000	-1.628E-02	948.		89.2	37.1	0.000
728.100	DANGER: CHANNEL 0	IBM				
728.200	CAUTION: CHANNEL 0	IBM				
728.300	DANGER: CHANNEL 0	IBM				
728.400	CAUTION: CHANNEL 0	IBM				
729.000	-2.134E-02	948.		89.2	37.1	0.000
729.600	COMMAND 5	S55				
730.000	-2.365E-03	0.000		0.000	34.8	0.000
731.000	-4.895E-03	0.000		0.000	34.8	0.000
732.000	-3.630E-03	0.000		0.000	34.8	0.000
733.000	-3.630E-03	0.000		0.000	34.8	0.000
734.000	-4.895E-03	0.000		0.000	34.8	0.000
735.000	-4.895E-03	0.000		0.000	34.9	0.000

Figure B9. Calibrated Hardcopy Output From the Data Printing Program. The operator can specify the number of channels to be printed (up to 10), the total time period to be processed, the time interval between data points to be processed, and printing of commands and warnings

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4→8